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Subdimensions of Social-Communication Impairment in Autism Spectrum Disorder

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Abstract

Background: More refined dimensions of social-communication impairment are needed to elucidate the clinical and biological boundaries of autism spectrum disorders (ASD) and other childhood onset psychiatric disorders associated with social difficulties, as well as to facilitate investigations in treatment and long-term outcomes of these disorders.

Methods: The current study was intended to identify separable dimensions of clinician-observed social-communication impairments, by examining scores on a widely used autism diagnostic instrument. Participants included verbally fluent children ages 3 to 13 years, who were given a clinical diagnosis of ASD (n=120) or non-ASD (i.e., ADHD, language disorder, intellectual disability, mood or anxiety disorder; n=118) following a comprehensive diagnostic assessment. Exploratory and confirmatory factor analysis examined the factor structure of algorithm items from the Autism Diagnostic Observation Schedule (ADOS), Module 3.

Results: Results indicated that a 3-factor model consisting of repetitive behaviors and two separate social-communication behavior factors had superior fit compared to a 2-factor model that included repetitive behaviors and one social-communication behavior factor. In the 3-factor model, impairments in "Basic Social-Communication" behaviors (e.g., eye contact, facial expressions, gestures) were separated from impairments in "Interaction Quality." Confirmatory factor analysis in an independent sample of children in the Simons Simplex Collection (SSC) further supported the division of social-communication impairments into these two factors. Scores in Interaction Quality were significantly associated with nonverbal IQ and male sex in the ASD group, and with age in the non-ASD group, while scores in Basic Social Communication were not significantly associated with any of these child characteristics in either diagnostic group.

Conclusions: Efforts to conceptualize level, or severity, of social-communication impairment in children with neurodevelopmental disorders might be facilitated by separating the most basic (or proximal) social-communication impairments, from those that could arise from a range of other phenotypic variables. Identification of social-communication sub-dimensions also highlights potential avenues for measuring different types of social-communication impairments for different purposes (e.g., for differential diagnosis vs. response to treatment).

Keywords: Autism severity, ADOS, Measurement, Basic Social-Communication, Interaction Quality

Introduction

An ongoing challenge for research in autism spectrum disorders (ASD) is how best to manage the heterogeneity of the clinical phenotype. Researchers have hoped that identifying symptom dimensions might facilitate investigations in genetics, neurobiology, treatment, and long-term outcomes, not only in ASD, but in a range of other childhood onset psychiatric disorders, as well (Chaste et al., 2014; Robertson, Tanguay, L'Ecuyer, Sims, & Waltrip, 1999; Wing & Gould, 1979). Because behaviors characteristic of ASD are observed in many clinical disorders and genetic syndromes, more refined dimensional measures are especially needed to elucidate the clinical, nosological, and biological boundaries of the multiple disorders associated with social-communication impairment (Casey et al., 2013; Lord & Jones, 2012).

In ASD, most studies have approached the question of symptom organization by factor analyzing widely used ASD measures like the Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003), Social Responsiveness Scale (SRS; Constantino & Gruber, 2005), or Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 1999). This has yielded a substantial body of literature indicating that ASD symptoms can be broadly organized into a social-communication domain and a restricted and repetitive behaviors (RRB) domain (Dworzynski, Happe, Bolton, & Ronald, 2009; Frazier et al., 2012), as is now reflected in DSM-5 criteria for ASD. However, within the broader construct of social-communication impairment, analyses have not been consistent in identifying replicable sub-domains.

One possible explanation for why factor analyses to date have not yielded narrower dimensions of social-communication behavior is that they have been carried out in samples mainly comprised of either children with ASD or typically developing individuals (Constantino & Todd, 2005; Lecavalier, Aman, Scahill, & McDougle, 2006). Because ASD symptom measures are specifically designed to characterize ASD, social-communication behaviors included in these measures may load together as a result of the fact that most people in the sample either do or do not have ASD. As a consequence, more fine grained distinctions in "type" of social-communication impairment that might otherwise be apparent in more diagnostically diverse samples could be overshadowed. In studies that have included more sizable groups of non-ASD participants (e.g., Gotham, Risi, Pickles, & Lord, 2007), factor analyses have been carried out mainly for the purpose of selecting best discriminating items, rather than to identify behavioral dimensions that might be expected to cross-cut diagnostic boundaries. Another issue is that when children with ASD are all grouped together, there is only a subset of items that can be examined in the entire group (e.g., certain language items only apply to verbal children). Thus, for the purposes of extracting sub-domains of social-communication symptoms, which can be highly susceptible to the effects of language level, age, and IQ, it may be necessary to look within more specific groups that are pre-stratified by relevant developmental variables.

The hope remains that identifying sub-dimensions within the broader domain of social-communication impairments could be useful in terms of classifying subgroups of children with ASD and other disorders for treatment and educational purposes, as well as for directing research efforts to link neurobiological mechanisms to specific types of behaviors. Constructing profiles of social-communication strengths/deficits could also be important for understanding the overlap between the categorical designation of ASD and other disorders that have clinical (e.g., differential diagnosis) and/or etiological (e.g., shared genetics) significance to ASD. To this end, and in an attempt to address the methodological limitations of previous studies on this topic, we examined the organizational structure of clinician observed social-communication deficits in a sample of verbally fluent children, half with ASD, and half with other disorders commonly associated with social problems.

Methods

Participants

Participants in the primary study sample were recruited as part of a larger project to validate a newly developed ASD screening tool. Eligibility for the larger study required that the child was between the ages of 2 and 12 years and had received a previous diagnosis of ASD or any one of a set of targeted non-ASD diagnoses. Targeted non-ASD diagnoses included ADHD, language disorder, intellectual disability (ID), and mood or anxiety disorder, which were selected due to known symptom overlap with ASD. Children who had been referred for a diagnostic evaluation because of significant parental or professional concern about ASD but who did not yet have a formal ASD diagnosis were also eligible. Children were excluded if they had a known genetic syndrome or a severe sensory (i.e., blindness, deafness) or motor impairment (i.e., not walking), but children of all IQ and language levels were otherwise eligible. Participants were recruited mainly through clinic intake/referral, flyers, or website communication, in the Divisions of Developmental and Behavioral Pediatrics and Behavioral Medicine and Clinical Psychology at Cincinnati Children's

Hospital Medical Center (CCHMC), or at the University of Michigan Autism and Communication Disorders Center (UMACC), which was a clinic specializing in ASD.

A total of 407 children were recruited, of whom the majority completed Module 3. Because the groups of children who completed Modules 1 or 2 of the ADOS were too small to permit separate analyses of items from those algorithms, the primary analyses were restricted to children who were administered Module 3. As shown in Table 1, this included 238 children ages 3 to 13 who were assigned a best estimate diagnosis of ASD (n=120) or non-ASD (n=118: including language disorder n=16; ADHD n=61; mood/anxiety disorder n=26; intellectual disability n=15) following completion of the study protocol (see Procedure below). However, significant item overlap between Modules 2 and 3 permitted inclusion of the Module 2 children (n=73) in certain follow-up analyses described below.

To ensure reproducibility of the results, analyses were subsequently conducted in a sample of children from the Simons Simplex Collection (SSC). Demographic characteristics for the SSC sample, N=1566, age range 4-17 years, all of whom had received a best estimate clinical diagnosis of ASD and met SSC inclusion criteria (see http://sfari.org/resources/sfari-base), are included in the supplemental material (see Appendix S1). Procedures related to the ascertainment and assessment of participants in the SSC are detailed elsewhere (see Fischbach & Lord, 2010).

TABLE 1

Procedure

As part of the research protocol, parents completed questionnaires and interviews, including the ADI-R. Children were administered a cognitive test and additional language testing as necessary to determine language impairment. All children also completed the ADOS, a standardized, semi-structured assessment of communication, social interaction, play, and imagination, which is designed for use in diagnostic evaluation of individuals with possible ASD. Module 1 is intended for children with simple phrase speech or less, Module 2 is for children with flexible phrase speech, and Module 3 is for use with verbally fluent children. The recently revised diagnostic algorithm for Module 3 includes 14 items; each item is scored on a 3-point scale from no evidence of the specified abnormality to marked abnormality (Gotham et al., 2007).

In the majority of cases, clinicians were kept blind to all previous diagnostic information about the participant until after the evaluation was completed. Introductory questions about diagnosis that are normally included in the ADI-R were moved to the end of the interview, and separate clinicians conducted the parent and child in-person assessments. However, in 17% of parent assessments, the examiner was given some information by the parent or another professional about the child's diagnostic status prior to beginning the ADI-R. In 13% of child assessments, the examiner was not blind to the child's previous diagnoses because he/she had also conducted the ADI-R administration for that participant.

Following the completion of all measures, clinicians met to discuss their impressions and assign a consensus clinical best-estimate diagnosis. Impressions from the ADI-R and ADOS were considered together with information from other measures, but algorithm total scores were not calculated until after the best-estimate clinical diagnosis had been assigned. Thus, diagnoses of ASD or non-ASD were assigned without formal knowledge of the ADI-R and/or ADOS algorithm totals. In addition, while participants were recruited into the study based on a previous diagnosis of ASD or one of the targeted non-ASD diagnoses, the ultimate designation of ASD vs. non-ASD used for the current analyses was based on the diagnostic assessment conducted as part of the research project as described above.

Data analysis

All factor analyses were performed with Mplus Version 7 (Muthén & Muthén, 1998-2012). Other analyses were undertaken in Stata Version 13.1 (Statacorp, 2013). Exploratory factor analysis (EFA) was used to determine the dimensional structure underlying the 14 behavioral indicators of ASD symptomatology on the Module 3 algorithm. There were no missing ADOS item data. The analyses were carried out with the robust weighted least squares estimator WLSMV, which has been recommended for analysis of ordered categorical data (Brown, 2006). Oblique rotation (geomin) was chosen based on the assumption that the dimensions may correlate with each other. A combination of statistical testing (e.g., chi square difference), mathematical and psychometric criteria (e.g., parallel analysis), and interpretability of factors was employed in determining the number of factors to extract. Models of one to five factors were examined based on the recommendation of more than two items per factor (Kline, 2011). Among the various methods available for identifying the correct number of factors, parallel analysis (PA) has been found to be the most accurate and recommended (Hayton, Allen, & Scarpello, 2004). PA entails comparing the eigenvalues obtained from the real data with eigenvalues obtained from simulated data of the same sample size and number of variables, in order to determine the number of real eigenvalues that outperform the random data (Hayton et al., 2004). PA was carried out with the *R* package random.polychor.pa (50 random simulations; 95th percentile of random eigenvalues) (Presaghi, Desimoni, & Presaghi, 2014).

Next, confirmatory factor analysis (CFA) was used to test whether the dimensionality suggested by EFA had significantly better fit compared to a two-dimensional model of ASD symptoms consisting of a social-communication factor and an RRB factor. Factor models were compared using the chi-square difference test of fit between nested models with a mean and variance adjusted chi-square statistic appropriate for WLSMV estimation (Muthén & Muthén, 1998-2012). Because the primary study sample was not large enough to allow exploratory and confirmatory analyses in separate sub-samples, confirmatory analysis was also conducted in an independent sample of Module 3 children with ASD from the Simons Simplex Collection (SSC).

Non-significant χ^2 is often used to determine goodness-of-fit for structural equation models. However, given that χ^2 is sensitive to sample size, model fit was also assessed with the root-mean-square error of approximation (RMSEA), the Bentler's comparative fit index (CFI; Bentler, 1990) and the Tucker-Lewis index (TLI; Muthén & Muthén, 1998-2012; Tucker & Lewis, 1973). In evaluating model fit, RMSEA cutoffs of 0.01, 0.05, and 0.08 were used to indicate excellent, good, and acceptable fit, respectively (MacCallum, Browne, & Sugawara, 1996). CFI $\geq$.96 and TLI $\geq$.95 have been suggested to indicate good fitting models (Hu & Bentler, 1999).

We examined whether the identified dimensions were differentially correlated with child characteristics previously associated with ASD symptom manifestation (i.e., age, IQ, and sex). Finally, logistic regression was used to examine the predictive value of the dimensions for diagnostic discrimination.

Results

Exploratory factor analysis

PA indicated that four factors should be retained. As shown in Table 2, the four-factor solution had good fit (non-significant X^2; RMSEA=0.03; CFI=1.0; TLI =1.0). The four factors were named Reporting, Interaction Quality, Basic Social-Communication (Basic SOC), and Restricted and Repetitive Behaviors (RRBs). Inspection of factor loadings revealed that the Reporting factor was primarily accounted for by only one item – *Reporting of Events* (.84, no other items >.38), which is a measure of how effectively the child is able to relate a non-routine and/or routine event. Given that *Reporting of Events* did not load on any of the three other factors (<.07) and the three-factor solution including this item yielded a less interpretable solution and a significant chi-square test, the item was excluded (Costello & Osborne, 2005). PA and model fit indices confirmed that variability in the remaining behavioral indicators was best explained by three factors (see Table 2).

TABLE 2

Fit indices for the three-factor model were all in the good to excellent range, $X^2(42)=52.52$, $p=.13$, RMSEA=.03, CFI=1.0, TLI=1.0. Table 3 presents the factor loadings for Basic SOC, Interaction Quality, and RRBs. The three items *Unusual Sensory Interest in Play Material/Person*, *Quality of Social Overtures*, and *Quality of Social Response* failed to show clear loading to one of the three factors (i.e. loading >.30 to any factor; differential loading >.10). Therefore, special attention was given to these items in the subsequent confirmatory analyses.

TABLE 3

Testing the factor model

Confirmatory analyses were used to examine whether the factor structure suggested by EFA could be replicated within a more constricted model as well as beyond the primary study sample. In the replication sample, model fit of the three-dimensional model was acceptable, $\chi2$ (62)=390.98, $p<.001$, RMSEA=.06, CFI=.95, TLI=.94.

TABLE 4

Among the three items without clear loadings in the primary sample, only *Quality of Social Overtures* also failed to load clearly to its specified factor in the CFA (modification index values=129.32, cross-loading with Interaction Quality). This cross-loading likely reflects the fact that the behaviors considered in the rating of this item rely on skills in both Basic Social-Communication (e.g., integration of nonverbal communication with speech) and Interaction Quality (e.g., bringing up appropriate conversation topics at appropriate times), as well as unusual behaviors also considered in RRBs (e.g., stereotyped or repetitive speech). Given that *Quality of Social Overtures* did not clearly load on either factor in EFA and CFA, and because the purpose of the current study was to identify separable sub-domains of social-communication impairment, this item was excluded. Therefore, the final model included four items for each of the three dimensions (all had score range 0-8). The fit of this model was good, $\chi 2$ (51)=241.03, p<.001, RMSEA=.05, CFI=.97, TLI=.96. All items also had clear loadings to their specified factor (>.30).

The final CFA model also had acceptable fit in the primary study sample ($\chi 2$ (51)=109.48; p<.001; RMSEA=.07; CFI=.99; TLI=.98), with all 12 items loading clearly to their specified factor (range: .54 to .98). Direct model comparison showed that the model distinguishing Basic Social-Communication, Interaction Quality, and RRBs had significantly better fit than the two-dimensional model consisting of a combined social-communication factor and an RRB factor. This was found in both the primary study sample ($\Delta\chi 2$ =15.85; df=2, p<.001), and in the replication sample ($\Delta\chi 2$ =156.04; df=2, p<.001).

Associations with child characteristics

Support for the distinction between the two social-communication dimensions was found with regard to their differential associations with child characteristics (see Table 5). Basic SOC was not significantly associated with age, nonverbal IQ, or sex, within either the ASD group or the non-ASD group. However, Interaction Quality was significantly associated with nonverbal IQ and male sex in the ASD group, and with age in the non-ASD group. The RRB factor was significantly associated with male sex in the ASD group, and with age in the non-ASD group.

TABLE 5

Associations with ASD diagnoses

In order to determine whether these factors might be generalizable to children without fluent language abilities, and because all of the social-communication items from the final CFA model are found in both Modules 2 and 3, analyses of diagnostic discrimination also included children who had received Module 2 (n=73; see Appendix S2 for Module 2 participant demographics). This yielded a total Module 2/Module 3 combined sample of 158 children with ASD and 153 with non-ASD diagnoses. Across diagnostic groups and modules, mean scores were the highest for Interaction Quality (see Appendix S3). The gap between scores on Basic SOC and Interaction quality was wider for children with non-ASD diagnoses (mean difference=1.10, SD=1.45) than for children with ASD diagnoses (mean difference=0.50, SD=1.84) (p=0.002). Predicting ASD versus non-ASD diagnoses from scores on the three ADOS dimensions, only Basic SOC and RRBs made independent, additive contributions (Basic SOC: B=0.73, OR=2.08, p<0.001, RRBs: B=0.95, OR=2.57, $p<0.001$), whereas Interaction Quality did not contribute significantly (B=0.06, OR=1.06, $p=0.67$), $\chi^2(3)=183.56$, $p<0.001$, Nagelgerke $R^2=0.71$. Stratified analyses by module showed that this pattern was consistent across children with phrase speech and fluent speech (Basic SOC and RRB $p\leq0.01$, Interaction Quality $p\geq0.93$).

Discussion

Results of the current study indicate that items from the ADOS Module 3 revised algorithm can be further separated into two sub-domains of social-communication impairments. The first group of ADOS social-communication items, which we refer to here as Basic Social-Communication, includes items measuring use of eye contact, facial expression, gesture, and shared enjoyment. Abnormalities in these behaviors are generally recognized as "core" impairments in ASD, and evidence from this and several previous studies suggests that they are remarkably intact in children who do not have ASD, even in the presence of significant other impairments or risk factors (e.g., children with severe intellectual disability, early trauma/neglect, prenatal teratogenic exposure, extreme prematurity; Bishop, Gahagan, & Lord, 2007; Rutter, Kreppner, & O'Connor, 2001). The second group of ADOS items, which we termed Interaction Quality, includes items that measure more complex aspects of dyadic social interaction, including *Amount of Reciprocal Social-Communication* (e.g., back and forth chat, initiations, responses), *Conversation*, and *Overall Quality of Rapport*, which is a measure of how hard the examiner must work to maintain a successful interaction. In the current study, scores in Interaction Quality were higher (more abnormal) than scores in Basic Social-Communication for both the ASD and non-ASD diagnostic groups, but children with non-ASD diagnoses exhibited a significantly larger gap between scores in the two sub-domains. Scores in Interaction Quality were significantly associated with nonverbal IQ and male sex in the ASD group, and with age in the non-ASD group, while scores in Basic Social Communication were not associated with any of the child characteristics in either diagnostic group. Furthermore, scores on the Basic Social-Communication and RRB sub-domains both made additive contributions to the prediction of ASD diagnosis (even after controlling for age, nonverbal IQ, and sex), whereas scores on Interaction Quality did not make a significant contribution.

The identification of separable dimensions of social-communication impairment is potentially significant for a number of reasons. First, consistent with several decades of research in ASD, basic impairments in nonverbal communication and shared affect emerged in this analysis as being quite specific to ASD (Bishop et al., 2007; Dawson, Hill, Spencer, Galpert, & Watson, 1990). Thus, if the goal is to describe ASD severity in its purest form, focusing on these impairments may be most appropriate. However, whereas in the present sample of primarily verbally fluent children, Basic Social-Communication abilities were relatively independent of age and IQ, these behaviors do vary across the full range of age, IQ, and language ability, such that younger children and/or those with low IQ or language abilities exhibit more severe impairments than older children and/or those with higher IQ and language ability (Lord & Pickles, 1996; Mundy, Sigman, & Kasari, 1994). Therefore, in order to detect differences in severity not accounted for by developmental variables, it is necessary to study sufficiently large samples within specific age by language level cells (e.g., toddlers with single word speech, school aged children with no functional language, adolescents with fluent language abilities). For example, the ADOS calibrated severity scores (CSS)/comparison scores were developed within specific age and expressive language level (Module) groupings, so unlike ADOS raw scores, individual differences in the CSS are not strongly related to IQ or age (Gotham, Pickles, & Lord, 2009; Hus, Gotham, & Lord, 2014).

Building on the ideas behind metrics like the CSS, our findings suggest that further isolating measures of Basic Social-Communication within age by language or IQ groups could provide an even more specific index of ASD severity than measures that combine items assessing Basic Social-Communication and Interaction Quality. Impairments in Interaction Quality appear to be less specific to ASD and are also more heavily influenced by other variables. Thus, to the extent that ASD severity is intended to measure “core” ASD impairments, including items related to Interaction Quality is problematic because the resulting score could reflect impaired Interaction Quality that does not arise from difficulties in Basic Social-Communication at all. Whereas for one child, a total score that combines both types of impairments might be measuring Basic Social-Communication abnormalities and their consequences; for another, a total score might reflect the consequences of other non-ASD-related behaviors that also affect Interaction Quality.

Given that Basic Social-Communication impairments appear to be relatively more specific to ASD, measures of Basic Social-Communication might provide a less confounded measure of ASD severity that would be particularly appealing for etiological research efforts. A challenge is that difficulties in Basic Social-Communication often become less obvious or more difficult to detect as children progress in age, IQ, and language, so it will be necessary to develop more subtle ways of capturing these impairments in order to represent the full spectrum of severity. This will likely require multiple types of technology, as well as large groups of relevant non-ASD controls, in order to achieve a greater understanding of what we should be looking for (e.g., frequency of interaction, social motivation) in children with varying degrees of cognitive and language abilities.

Limitations

This study offers a number of exciting directions for future study of sub-dimensions of social-communication impairments in ASD, but it is important to acknowledge the somewhat selective nature of our sample. Verbally fluent school aged children represent a sizable segment of the general ASD population (CDC, 2014), but the applicability of a two factor model of social-communication impairment needs to be directly tested in younger and/or less verbal children with ASD and non-ASD diagnoses. Sub-dimensions of social-communication impairment should also be explored in contexts outside of the ADOS, which is designed to measure a specific set of behaviors that occur in interactions between a child and an unfamiliar adult, and which may not reflect the full range of behaviors apparent in interactions with family members or peers, for example.

Conclusion

Results of this study corroborate observations by others (American Psychiatric Association, 2013; Hus et al., 2014; Weitlauf, Gotham, Vehorn, & Warren, 2014) that "severity" of ASD-related impairment is a multi-dimensional construct that can be influenced by a multitude of individual, contextual, and measurement factors. Appropriate measurement of ASD symptoms therefore requires a nuanced approach that considers the contribution of different types of social-communication impairments and repetitive behaviors and that is tailored to the specific population and research question (Lord & Jones, 2012). Our findings offer new insights into potential strategies for considering different types of social-communication impairments for different purposes. From the perspective of differential diagnosis and etiological underpinnings of ASD, it will likely be useful to differentiate behaviors that are most specific and/or most proximal from those that may be distal consequences of other behaviors (e.g., hyperactivity/impulsivity) and/or deficits (e.g., intellectual disability). However, from a clinical service perspective, although there are multiple roads to poor quality interaction, with only some of them arising from impairments in the most basic aspects of social-communication, all of these paths can lead to very real problems in social functioning for children across diagnostic categories.

Key Points

- Identifying replicable sub-domains of social-communication impairment has the potential to facilitate research in ASD and other disorders associated with social impairment.
- In a sample of verbally fluent children, half with ASD and half with non-ASD diagnoses, we identified two separable sub-domains of social-communication impairment.
- Basic Social-Communication impairments, which included items measuring eye contact, facial expression, gesture, and shared enjoyment, were more predictive of an ASD diagnosis, and scores on these items were not significantly associated with sex, age, or nonverbal IQ.
- Impairments in Interaction Quality, which included items that measure more complex aspects of dyadic social interaction, were significantly associated with sex, age, and nonverbal IQ.
- These findings offer new insights into potential strategies for considering different types of social-communication impairments for different purposes.

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Table 1. Participant characteristics: Primary study sample

Characteristic	ASD (n=120)	Non-ASD (n=118)	t/X^2
Age in years, m (SD)	8.7 (2.4)	8.5 (2.4)	0.6
Sex, male, n [%]	93 [77.5]	79 [66.9]	3.3
Caucasian/white ethnicity, n [%]	94 [78.3]	71 [60.7]	8.7**
Nonverbal IQ, m (SD)	97.6 (19.6)	95.3 (17.3)	1.0
Verbal IQ, m (SD)	94.7 (17.5)	96.1 (18.1)	-0.6
ADOS comparison score	7.3 (2.1)	2.6 (2.1)	17.5***

Note. ASD=autism spectrum disorder, ADOS=autism diagnostic observation schedule.

p<.01,*p<.001.

Table 2. Comparison of exploratory factor models

All 14 algorithm items					
Number of factors	Eigenvalues	χ2	df	RMSEA	Δχ2
1	7.59	222.70***	77	0.09	-
2	1.48	121.18***	64	0.06	82.31***
3	1.00	75.10*	52	0.04	40.80***
4	0.94	51.05	41	0.03	23.10*
5	0.74	33.45	31	0.02	16.99
13 algorithm items (*Reporting of Events* excluded)					
Number of factors	Eigenvalues	χ2	df	RMSEA	Δχ2
1	7.31	193.06***	65	0.09	-
2	1.45	86.33**	53	0.05	81.52***
3	1.00	52.52	42	0.03	29.97**
4	0.75	36.22	32	0.02	15.92
5	0.64	20.81	23	<.01	15.38

Note: χ2 = Chi-square (non-significant values suggest good fit), df= degrees of freedom, RMSEA = Root Mean Square Error of Approximation (≤0.05 suggest good fit), Δχ2 Chi-square difference for model comparison (non-significant value suggests no better fit than the model with one less factor). *p<.05,**p<.01,***p<.001.

Table 3. Item factor loadings and factor correlations from exploratory factor analysis (N=238)

	Dimensions		
	Basic SOC	Interaction Quality	RRB
Social affect			
Descriptive gestures	**.83**		
Unusual eye contact	**.71**		
Facial expressions	**.85**		
Shared enjoyment	**.64**	.34	
Quality of social overtures	.48		.49
Conversation		**.54**	
Amount of reciprocal social communication	.37	**.70**	
Overall quality of rapport		**.54**	.37
Quality of social response		.54	.47
RRBs			
Stereotyped speech			**.97**
Mannerisms			**.41**
Excessive interest			**.72**
Sensory interest			(.15)
Factor correlations	Basic SOC	Interaction Quality	RRB
Basic SOC	1		
Interaction Quality	.70***	1	
RRB	.54**	.54**	1

Note: ADOS=autism diagnostic observation schedule, SOC = social-communication, RRB = restricted and repetitive behavior. All parameters are completely standardized. Factor loadings larger than .32 are shown to enhance interpretability (exception for "Sensory interest" which had no significant loading to any factor). Bolded: Clear loading to one factor. **p<.01, ***p<.001.

Table 4. Results from the confirmatory factor analysis in the replication sample (N=1566)

	Dimensions		
	Basic SOC	Interaction Quality	RRB
Social affect			
Descriptive gestures	.41		
Unusual eye contact	.31		
Facial expressions	.65		
Shared enjoyment	.86		
Conversation		.75	
Amount of reciprocal Social-Communication		.83	
Overall quality of rapport		.71	
Quality of social response		.76	
RRBs			
Stereotyped speech			.61
Excessive interest			.39
Mannerisms			.44
Sensory interest			.44
Correlations	F1	F2	F3
Basic SOC (F1)	1		
Interaction Quality (F2)	.69***	1	
RRBs (F3)	.17***	.47***	1

Note: SOC = social-communication, RRBs = restricted and repetitive behavior. All parameters are completely standardized. ***p<.001.

Table 5. Associations between the ASD symptom dimensions and child characteristics

	ASD (n=120)		Non-ASD (n=118)	
	Pearson *r*	*p*	Pearson *r*	*p*
Basic SOC				
Nonverbal IQ	-0.15	.10	-0.01	.92
Age	-0.04	.63	0.02	.80
Male	0.12	.18	0.14	.13
Interaction Quality				
Nonverbal IQ	-0.21	.02	-0.10	.28
Age	-0.07	.46	-0.21	.02
Male	0.20	.03	0.05	.59
RRBs				
Nonverbal IQ	>0.01	>.99	-0.09	.35
Age	-0.17	.06	-0.30	<.01
Male	0.21	.02	0.07	.46

Note: ASD=autism spectrum disorder. SOC=Social-Communication, RRB = restricted and repetitive behavior